National Aeronautics and Space Administration

FY24 Strategic Initiatives Research and Technology Development (SRTD)

Active Structural Impedance Match for Damping Ultra-Stable Telescopes

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Strategic Focus Area: Starlight Suppression | **Strategic Initiative Leader:** David W Miller

Objectives & Background:

Structural Impedance Matching (SIM) has its origins at MIT and arises by viewing the structure as a connection of vibrational waveguides along which energy propagates. At discontinuities in the structure, this energy scatters (i.e., gets reflected, transmitted, or absorbed). Waves that return in a manner that creates a constructive interference will correspond to resonances. Those that return in as a destructive interference will correspond to zeros in the control matrix. Through active control, the reflection and transmission coefficients at these discontinuities can be altered. This technique is used terrestrially in high voltage power transmission systems to prevent reflection at sub-stations. If instead both the reflection and transmission coefficients are zeroed, all the energy arriving at the discontinuity is absorbed and dissipated as heat in the controller electronics. The goal is to expand MIT's work in two ways: 1) zero all reflection and transmission coefficients at the bus-side of an isolator leading to the Observatory's Payload, and 2) extend the bandwidth over which this occurs. SIM offers a broad band reduction in vibrations that can be effective where passive isolation (current state of the art) cannot be effective (i.e., the pass band of the isolator), and while simplifying the interface design between SC and telescope.

Figure 1

Partial Structural Impedance Matching (IM) @ MIT

On a slender, uniform bending beam at pinned B.C.

- Objective:
  - To eliminate resonant behavior by zeroing reflection coefficient at pinned end
  - By applying active control that converts incident bending waves into heat
  - While robust by using positive real, phase stable, feedback compensators
- Notice that de-reverberated transfer function magnitude goes as $s^{-4/3}$
- Rate feedback law: $M = 3sv'$ chosen to minimize response at 10 Hz
- Noncausal, partial IM: $M = \sqrt{2}c_o EI\sqrt{-s}v'$ where $c_o = \sqrt[4]{\rho A/EI}$
- Causal, partial IM: $M = \frac{8c_o EI}{5\sqrt[4]{\omega_n}}\frac{s^2}{s+92}\frac{1}{\sqrt[4]{s}}v'$ to minimize response at 10 Hz
- Now consider IM at free boundary condition
  - Full causal negative feedback IM: $\begin{Bmatrix} F \\ M \end{Bmatrix} = EI\begin{bmatrix} -\sqrt{2}c_o^3 s^{1/2} & c_o^2 \\ c_o^2 & -\sqrt{2}c_o s^{-1/2} \end{bmatrix}\begin{Bmatrix} sv \\ sv' \end{Bmatrix}$
  - Mimics forces & torques that would occur if equivalent semi-infinite beam was attached
- Full IM requires sensing and actuation of all DOFs at the structural cross-section
  - Control law only depends on de-reverberated transfer function

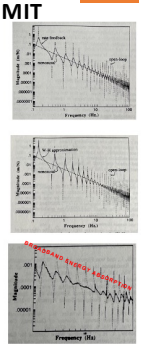


Figure 2a

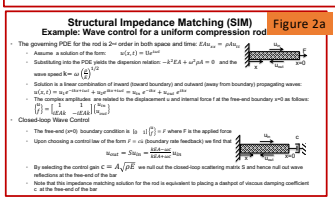
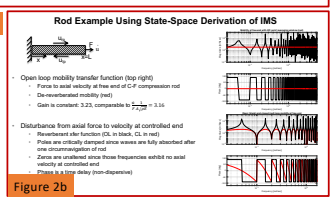


Figure 2b

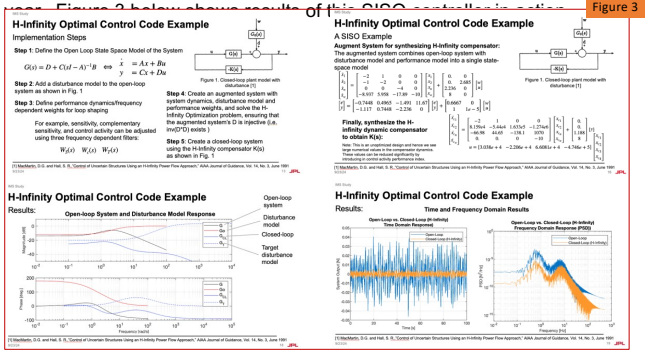


Approach & Results:

This year's focus was on ***i)*** identifying infusion opportunities, ***ii)*** building design tools, and ***iii)*** building modeling & simulation methodologies for IMS. Next year's focus will be on designing and implementing IMS using the H-infinity technique developed this year on a Telescope

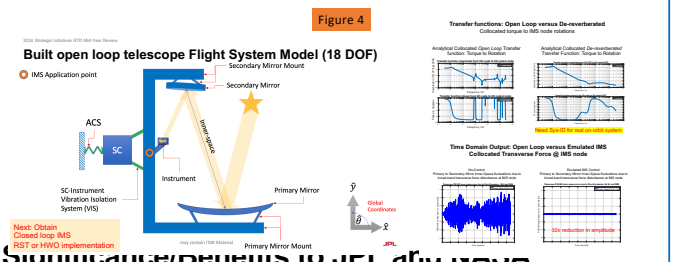
1. Identified infusion opportunities to HWO and telescopes with tight stability requirements in general.
2. Reviewed impedance matching principles. Both a single Degree of freedom bar (figure 4) and a 2 degree of freedom bending beam SIM (figures 2a, and 2b) development was reviewed and completed by the team.
3. Developed H-infinity methods to develop causal SIM controllers. A SISO SIM controller designed through this H-infinity method developed here has been completed for the first time and will be extended to a 12dof SIM next year. Figure 3 below shows results of this SISO controller in action.

Figure 3



4. Developed a planar telescope system and associated finite element model. This model (figure 4) will be used to test out a 6DOF SIM controller next year. This system will be extended to a full three-dimensional design/model next year so we can test out the 12DOF H-infinity SIM design.

Figure 4



Significance/Benefits to JPL and NASA:

NASA has recently stood up the Habitable Worlds Observatory (HWO) Project, which will be their next Large Flagship Observatory after James Web and Roman Space Telescopes. HWO's main instrument is a set of coronagraphs requiring wavefront stability in the 10s of picometers! Which is hundreds of times more stringent than what these other Telescopes have needed. The work being done here will generate active broad band energy dissipation techniques, which together with other efforts (like micro-thrusters for ACS) being developed by JPL and other NASA centers, will help achieve the unprecedented levels of stability needed by HWO and future telescopes

References:
[1] MacMartin, D.G. and Hall, S. R.,"Control of Uncertain Structures Using an H-Infinity Power Flow Approach," AIAA Journal of Guidance, Vol. 14, No. 3, June 1991
[2] Boyd S., Balakrishnan, V., "On Computing the H Infinity Norm of a Transfer Matrix," Proc. American Control Conference, Atlanta, Georgia, 1988

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